Experimental Demonstration of Contoured Beam Reflectarrays for Satellite Applications

Eng. J. Agustin Zornoza, Prof. Jose A. Encinar, Polytechnic University of Madrid-Spain
Eng. Markus Frantz, Dr. Leri Datashvili, Prof. Horst Baier, Lehrstuhl für Leichtbau, TU München-Germany
Prof. M. Sierra-Castaner, Eng. Pablo Caballero, Prof. Jose L. Besada, Polytechnic University of Madrid-Spain

Abstract

A three-layer refletarray with patches of variable size that radiates a contoured beam at Ku-band defined for Eutelsat satellite W3A at 7º East has been designed, manufactured and tested. A square reflectarray of side 1-m has been considered. For electrical design, first a phase-only synthesis technique based on the *alternating projection method* has been applied to obtain the phase distribution on the reflectarray surface for the specified contoured beam; and then, the patch dimensions are adjusted at each radiating element to achieve this phase distribution at several frequencies in the working band for dual linear polarisation. An appropriate mechanical design has been carried out, in order to minimise possible thermo-elastic distortions. A breadboard has been manufactured and measured in anechoic chamber. The results show a contoured beam close to the required coverage.

1 Introduction

Printed reflectarrays can be an alternative to the on-board shaped reflectors used in space applications, due to their lower cost, simple development and ease of deployment. A contoured beam reflectarray was demonstrated in [1] for DBS applications using a single layer printed reflectarray with patches of variable size. However, this breadboard suffered from the bandwidth limitations inherent in single layer reflectarrays.

A technique was proposed in [2] to improve the bandwidth behaviour using a three-layer reflectarray with patches of variable size (see **Fig. 1**). Using a phase-only synthesis technique, an 80-cm three–layer reflectarray has been designed for a South America coverage at Ku-band for a 10% bandwidth [3]. The aim of this contribution is to present experimental results for the mechanical and electrical performances of a contoured beam reflectarray at Ku band, designed by the techniques described in [2,3].

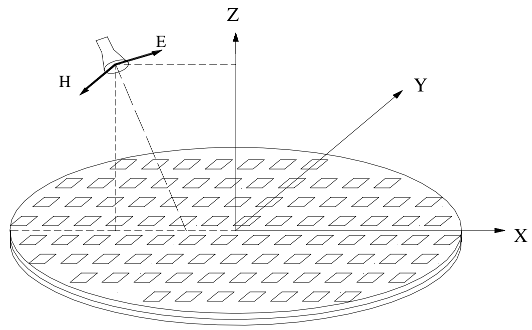


Fig. 1 Multi-layer printed reflectarray with an offset feed

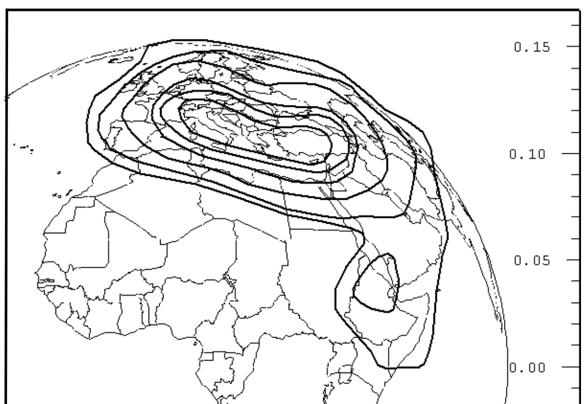


Fig. 2 Coverage for Eutelsat W3A at 7º east (contours correspond to 51, 50, 49, 46, 43 and 41 dBW)

2 Reflectarray Design

2.1 Subsystem definition

An European coverage defined for Eutelsat satellite W3A at 7º East in the frequency band 10.7-11.7 GHz has been chosen (see **Fig. 2**). Currently a 1.4-m reflector antenna is used for this mission (transmit). For the reflectarray design, a flat square surface of $1m^2$ has been selected and the feed is located with its phase centre at coordinates x_f= -322, y_f=0, z_f=1186 mm.

An X-band standard gain horn from Narda has been used, and its radiation pattern is simulated as a $cos^{13}(\theta)$, with a –8 dB taper at the reflectarray principal planes. The patches in each layer are arranged in a 16mmx16mm square lattice to avoid the appearance of grating lobes (62x62 periodic cells).

2.2 Pattern Synthesis

A phase-only synthesis technique based on the *alternating projection method* has been applied to obtain the phase distribution on the reflectarray surface at central frequency (11.2 GHz) for the specified contoured beam [3]. Considering an out of focus pencil beam for the initial phase distribution, the synthesis procedure is applied and the required phase for the reflection coefficient on each element at 11.2 GHz is achieved (see **Fig. 3**).

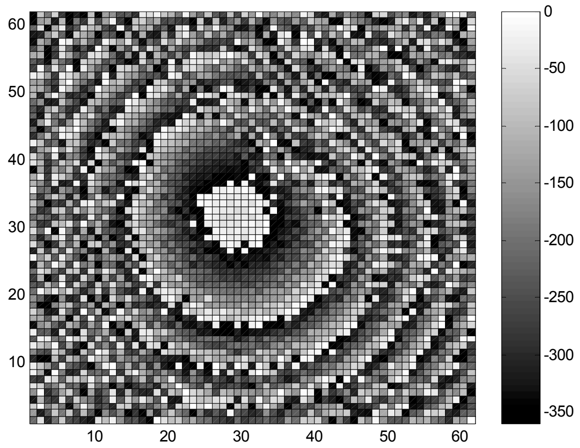


Fig. 3 Required phase of reflection coefficient for the coverage of Fig. 2

2.3 Mechanical design of the sandwich

A symmetrical layer configuration, shown in **Fig. 4** has been chosen to implement the flat sandwich panel. The basic idea of this design is to sandwich all printed arrays with a quasi-isotropic composite material of Kevlar in order to lower the coefficient of thermal extension. The proposed configuration will prevent the extension of the copper patches and will minimize the plate curvatures at thermal loads.

2.4 Design of printed patches

The patches in each layer are printed on a Kapton film with 0.086 mm Kevlar skin on both sides, and separated by 3mm-thick Rohacell. The design of the reflectarray is performed element by element. First, the patch dimensions are adjusted to produce the required phase distribution at the central frequency, but maintaining a fixed relative patch size in each stacked array, ($a_1=0.6a_3$, $a_2=0.9a_3$, $b_1=0.6b_3$, $b_2=0.9b_3$, being a_i x b_i the dimensions of a patch at layer *i* as defined in **Fig. 5**). At this stage, the dimensions of the stacked rectangular patches are adjusted in each cell to match the objective phase by a zero search routine that calls iteratively an analysis routine based on the *Method of Moments*, as described in [4]. Then, an optimisation technique was applied and the dimensions of the patches in the three layers were adjusted independently to match the required phase at central and extreme frequencies in the 10.7-11.7 GHz band.

The methods for design and analysis were validated in [4] by manufacture and test of a two-layer reflectarray for a pencil beam. For dual or circular polarization, both patch dimensions are independently adjusted to obtain the suitable phase distribution for each orthogonal polarization.

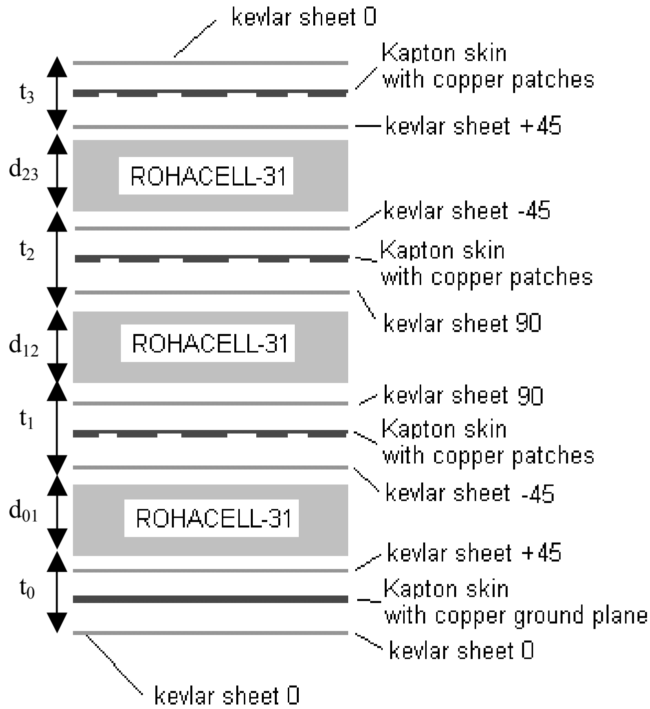
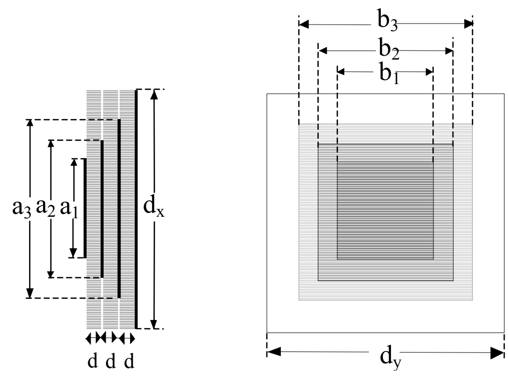


Fig.4 Sandwich configuration



(a) (b)

Fig. 5 Periodic cell of a three-layer reflectarray. (a) Lateral view. (b) Front view.

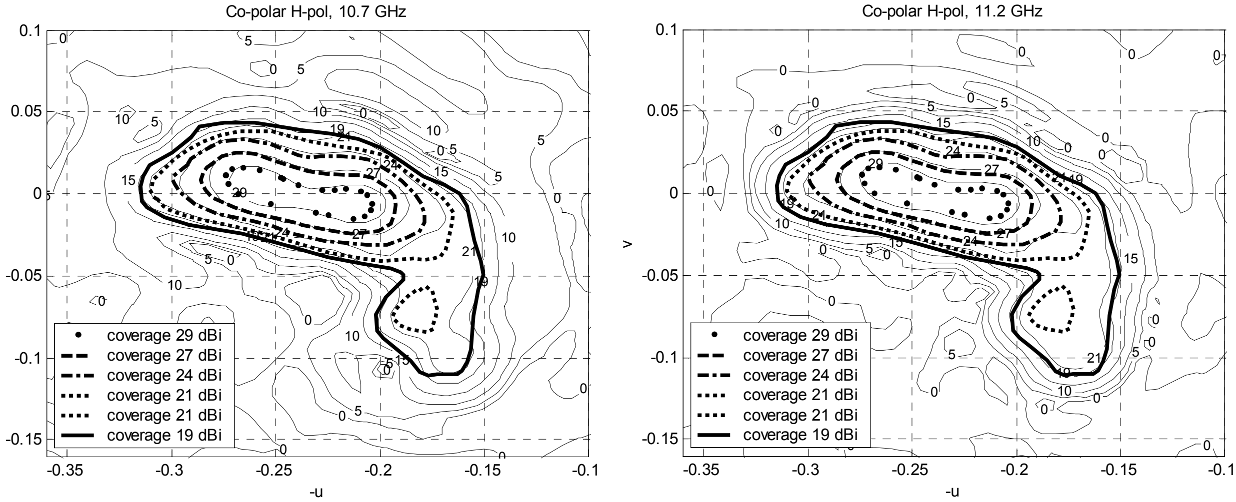


Fig. 6 Theoretical gain contours for H polarisation superimposed onto the contoured requirements at lower and central frequency.

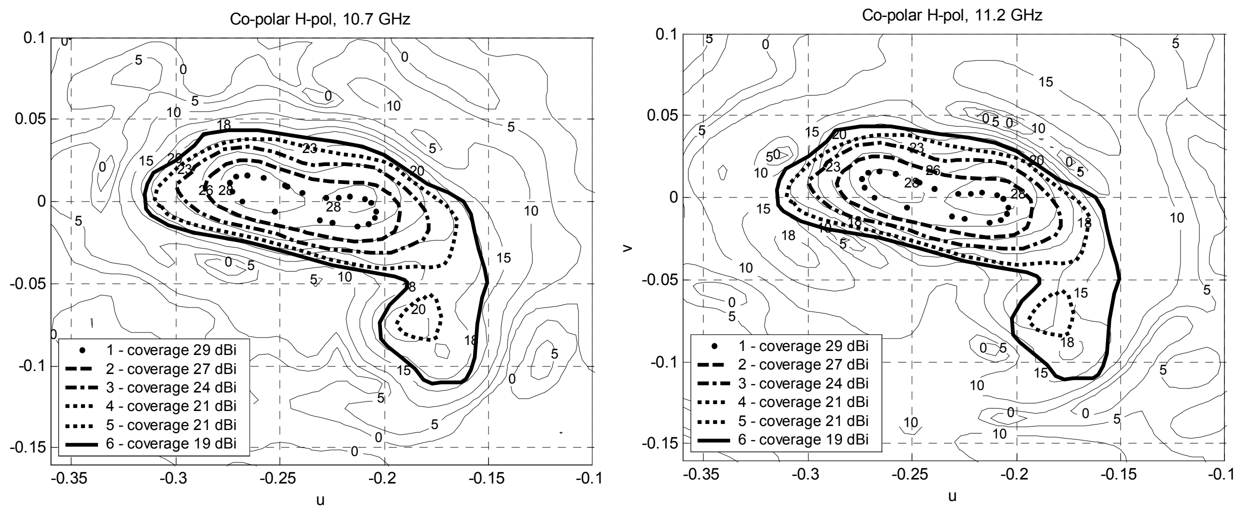


Fig. 8 Measured gain contours for H polarisation superimposed onto the contoured requirements at lower and central frequency.

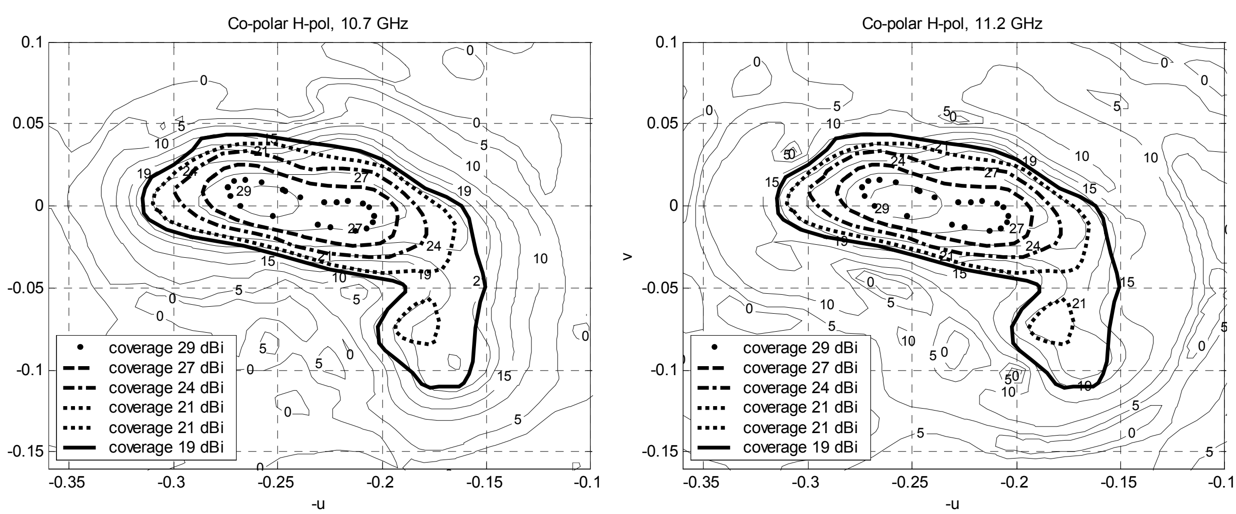


Fig. 9 Computed gain contours for H polarisation for measured thickness of dielectric layers.

The computed gain contours for H polarization are represented in **Fig. 6** superimposed onto the contour requirements at 10.7 and 11.2 GHz. Similar patterns are obtained for 11.7 GHz and for V polarization. The magnitude represented here is the gain of the antenna in dBi, since the power radiated by the reflectarray has been divided by the total power radiated by the feed.

3 Experimental Results

The manufactured three-layer reflectarray panel has been measured in anechoic chamber using a planar near field scanner (see **Fig. 7**). The antenna pattern and gain measurements were realized in an useful area of 190 cm x 190 cm, at 10.7, 11.2 and 11.7 GHz. The distance between the probe and antenna under test was 174 cm, so the angular validity of the measurements (for the dimensions of this reflectarray) is 14.5º. The antenna gain was computed with the direct gain measurement method [5], using the probe as the gain standard.

Fig. 7 Manufactured three-layer reflectarray panel and planar near field scanner.

Measured gain contours for H polarization are shown in **Fig. 8** at 10.7 and 11.2 GHz. Contours close to the requirements are obtained at 10.7 GHz, however, significant distortions are observed at 11.2 GHz and even more at 11.7 GHz (not represented). The main reasons for the discrepancies are manufacture errors in the breadboard, and particularly those on thickness of dielectric layers in the sandwich. Table 1 shows nominal and measured values for thickness of each layer in three different points of the panel. It was demonstrated with simulations that the most critical tolerances are those in thickness of Kevlar layers due to their higher dielectric constant. The effect of an increase of this thickness, as measured in the breadboard, is to increase the effective dielectric constant and then to reduce the resonance frequency of the patches. In consequence, the degradation is higher for higher frequencies. The radiation patterns have been computed for average values of measured thickness (170 microns for each kevlar layer and 2.6, 2.8 and 2.9mm for Rohacell), see **Fig. 9**. The resulting patterns show a significant distortion, but still they do not reproduce the measured contours because the thickness of the different layers are not uniform in the whole panel, and also because other tolerances are not included.

Table 1.

Thickness measured on three points [mm]								
Point	t_{tot}	t_0	t_1	t_2	t_3	d_{01}	d_{12}	d_{23}
1	**9.68**	**0.41**	**0.38**	**0.36**	**0.37**	**2.63**	**2.72**	**2.78**
2	**10.56**	**0.41**	**0.40**	**0.40**	**0.40**	**2.94**	**2.96**	**2.96**
3	**9.64**	**0.40**	**0.37**	**0.39**	**0.37**	**2.53**	**2.81**	**2.88**
Nominal	**10.04**	**0.26** (0.086+0.035+0.05+0.086)				**3.0**		

4 Conclusions

A contoured beam reflectarray for a DBS European coverage has been demonstrated. Some distortion of the patterns were observed due to significant differences in nominal and measured thickness of kevlar layers and other tolerance errors. In conclusion, thickness of Kevlar layer is very critical and must be known with high accuracy for the electrical design.

5 Literature

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